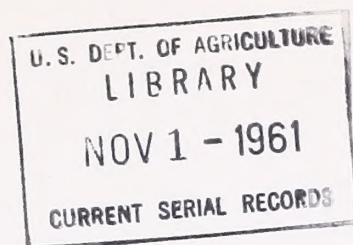


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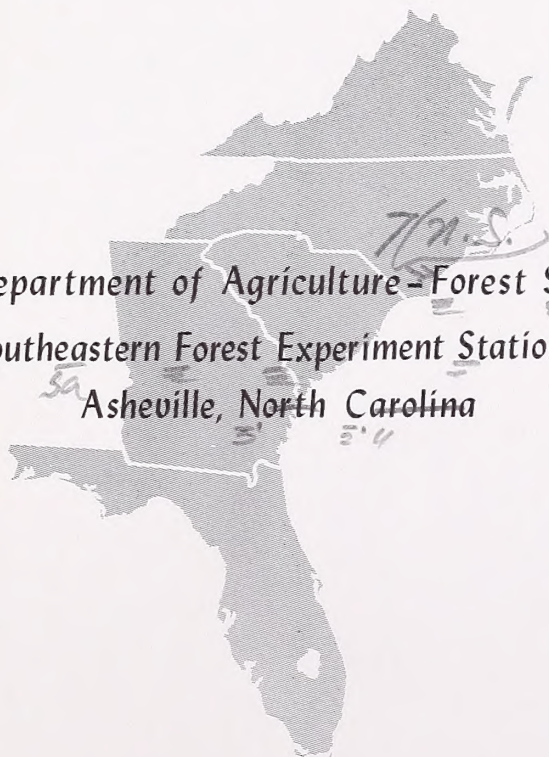
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(SOME APPLICATIONS OF DANGER RATINGS
IN
FOREST FIRE CONTROL AND MANAGEMENT //

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Many workers have contributed to the development of uses of fire danger measurements and procedures discussed in this paper. Principal acknowledgment is due J. J. Keetch who gave many helpful suggestions during the preparation of this report.

SOME APPLICATIONS OF DANGER RATINGS

IN

FOREST FIRE CONTROL AND MANAGEMENT

by

Ralph M. Nelson

INTRODUCTION

The system of measuring forest fire danger developed at the Southeastern Forest Experiment Station is used throughout the Eastern and Southern regions of the United States. At last count, 814 fire danger stations were operated by state, federal, and private fire control agencies in these regions. Although a number of publications have been issued on the location, operation, and maintenance of danger stations, there is only fragmentary published material on the many possible uses and applications of danger measurements.

The purpose of this paper is to summarize and explain the major uses of fire danger ratings and to present methods of analyzing fire and fire danger records. All uses are not listed, and all may not be applicable in every protection unit, but those described have been found useful in specific areas.

DERIVATION OF BURNING AND BUILDUP INDEXES

Before discussing the application of danger measurements, the system used in measuring danger in the East and South (2, 6, 8) should be briefly described. Four variables are taken into account: dryness or greenness of lesser vegetation, wind speed, upper fuel (thin surface layer) moisture as estimated from thin basswood slats, and relative dryness of lower fuels called the buildup index. When these variables are integrated on the type 8 meter used in the East, or its counterpart type 8-100 used in the South, the degree of danger is indicated on a numerical scale^{1/} called the burning index. The low part of the scale indicates little danger, the upper part high to extreme danger.

^{1/} Type 8 meter has a burning index scale of 1 to 200, the type 8-100 of 1 to 100; in other respects the two types are similar.

The buildup index has a 100-point scale and is an indicator of the relative dryness of the several inches of fuel beneath the upper thin layer. It is obtained by cumulating drying factors based on the upper fuel moisture content as measured by thin basswood slats during rainless periods. It is reduced according to the amount of rain. For example, the index will reach its maximum of 100 points after 10 consecutive rainless days when the upper fuel moisture is less than 4 percent, or after 20 days when the moisture percent is in the 6.0 to 6.9 range. The index is reduced by one point for every hundredth inch of rain.

SIGNIFICANCE OF BURNING AND BUILDUP INDEXES

The burning index is primarily an indicator of the probability of fires starting in that it combines two major elements conducive to fuel flammability, fuel dryness and wind. Therefore, the number of fires in general increase as the index increases. This relation is illustrated by an analysis of fires and burning index for 1959 for one of the Southern States (table 1). As will be seen, there were almost 6 times as many fires per day in the 20 to 45 range as in the 2 to 5 range during the severest months and only slightly less in the other months. Similar positive correlations have been found to hold in all areas when such analyses have been made.

Table 1.--Fires per day by burning index ranges and seasons.^{1/} Data are for a Southern State, 1959

Burning ^{2/} index range	January, February, March, April, December			May through November		
	Fires	Days	Fires per day	Fires	Days	Fires per day
	----- <u>Number</u> -----					
0 to 1	46	310	0.15	273	1150	0.24
2 to 5	754	443	1.7	652	769	0.85
6 to 17	2773	613	4.5	460	208	2.2
20 to 45	1421	144	9.9	43	9	4.8
50+	0	0	0	0	0	0

^{1/} Number of fires and days are totals for the 10 districts in the state.

^{2/} Type 8-100-0 meter. The index ranges are equivalent to danger classes on this type meter.

Rate of spread and fire intensity are also related to burning index. Keetch (4) has described the probable behavior of fires according to burning index ranges as follows:

BURNING INDEX		RELATIVE FIRE DANGER DESCRIPTIONS
METER 8	METER 8-100	
1 to 2	1	<p><u>Low Fire Danger</u></p> <p>Cured grass may burn freely in the open a few hours after rain, but there is little danger of accidental fires in the forest. An occasional low-intensity woods fire may occur as the forest litter dries out. Such fires usually creep or smoulder, have irregular fingers, and consume only a portion of the surface litter. There is little danger of spotting, even with fairly high winds.</p>
3 to 11	2 to 5	<p><u>Moderate Fire Danger</u></p> <p>Fires in open cured grassland will burn briskly and spread rapidly with the wind. Woods fires start easily and spread slowly to moderately fast. The average fire in pine or hardwood litter is of moderate intensity, although heavy concentrations of draped fuel may burn hot. Short-distance spotting over the line may occur, but is usually not persistent.</p>
12 to 35	6 to 17	<p><u>Medium (or Average) Fire Danger</u></p> <p>All fine forest fuels ignite readily, and as fire intensity builds up, twigs and small brush usually become part of the available fuel. The rate of spread on level terrain is rapid, and though fires proceed primarily as a flame front, short-distance spotting is common. Unattended brush and camp fires are likely to escape. Control of fires may be of more than average difficulty, especially in the upper burning index ranges of the medium fire danger condition, unless fires are hit hard and fast. Fires burning upslope, especially if the prevailing wind is with the slope, may spread furiously and may temporarily assume characteristics of the high fire danger condition.</p>

40 to 95	20 to 45	<p style="text-align: center;"><u>High Fire Danger</u></p> <p>Fires in the very dry fuels characteristic of the high fire danger condition will immediately after ignition spread rapidly, and increase quickly in intensity. There is usually considerable spotting over the line, and because of the dry fuels, spot fires are a constant danger. High-intensity fires may develop intense convection activity to a considerable height, evidenced by dark rolls and surges in the smoke column above the fire front. A favorable condition for this development is a decreasing wind aloft above a strong ground wind (described as an adverse wind profile). The worst features of high-intensity burning, such as long-distance spotting, fire whirlwinds, and strong updrafts and downdrafts, are associated with the well-developed smoke column. Fires burning in light fuels may quickly develop high-intensity characteristics when they burn into heavier fuels, or the triggering mechanism may be the result of an upslope run or two fires burning together without a change in fuel type.</p>
100 to 200	50 to 100	<p style="text-align: center;"><u>Extreme Fire Danger</u></p> <p>Fires in all fuel types may burn intensely and spread furiously. Crowning and spot fires are common. Development into high-intensity burning will usually be faster and occur in the case of smaller fires than in the high fire danger condition. Fires may quickly develop a high-intensity head, or heads, each with its own active smoke column, when adverse wind profiles are present. Fires that develop headway in heavy slash or dense conifer stands may be unmanageable until the weather subsides or the fuel supply lessens.</p>

The buildup index, as previously explained, indicates the relative dryness of several inches of fuel beneath the thin upper layer. As more fuel becomes available through progressively deeper drying, the rate of energy release from fires also becomes greater. Under similar conditions of upper fuel moisture and weather, fires will burn more intensely and will be more difficult to control when the buildup index is high than when it is low. When the index approaches its maximum, fuel layers, and to some extent the mineral soil beneath, become extremely dry. At such times firelines are hard to hold and mop up becomes increasingly difficult. On many occasions fires thought to be under control have crept under firelines in buried material and kindled fuels on the other side. Deep duff fuels or organic soils respond differently to wetting and drying than ordinary fuels on mineral soils. The buildup index therefore is not a good indicator of the relative dryness of these deep fuels.

Although in general, number of fires and acres burned increase as the burning index increases, wide differences are sometimes found among days and protection units having the same burning index. For example, 5 fires may occur in a protection unit on a day with a burning index of 50 and none at all on another 50-index day. These differences occur because of the unpredictable activity of fire starters. Nevertheless, a day with a certain burning index has a certain fire potential whether many or no fires occur.

The burning and buildup indexes described provide the fire control manager with meaningful numbers that indicate probable fire occurrence, rate of spread, intensity, and resistance to control. When intelligently interpreted in terms of fuel types and terrain, the indexes supply a highly useful basis for day-to-day fire control planning and action.

USE OF DANGER RATINGS IN PREPAREDNESS PLANNING

Fire danger in the East and South, unlike some western regions where danger normally builds to a seasonal peak which persists for long periods, can fluctuate greatly from day to day. For this reason it is only during exceptional years that a fire control organization must be maintained at full strength for extended periods. To do so in an average year would be unjustifiably wasteful. To be most effective, however, fire control forces must be organized to adjust promptly to easy days and difficult days that often follow each other in quick succession.

Few if any fire control organizations are large enough and flexible enough to cope with the "worst probable" fire load. The prudent fire control supervisor should, however, have sufficient knowledge of his terrain, fuel types, danger ratings, and probable risk, as well as suppression facilities available, to meet "average bad" conditions with prompt and effective action. In addition he should know when extreme danger impends so that extraordinary precautions can be taken.

Attempting to meet fire situations as they arise without advance planning is likely to be costly and ineffective, as has been abundantly demonstrated in the past. An action plan based on the calculation of probabilities, that is the probable number of fires that will start and how they will behave, is essential to the soundest disposition of control forces. Such plans have been developed from judgment alone, but analysis of past measured danger as related to fire occurrence and behavior can take out much of the guesswork in their preparation.

As a first step in preparedness planning, an analysis of number of days, fires, and acres burned by burning index ranges for a period of several years is suggested for each protection unit. Table 2 is a sample analysis. It is clear from the tabulation that a decided increase in the fire load can be expected with an increase in the burning index range, although its load size varies by seasons.

Table 2.--Days, fires, and acres burned by burning index ranges and seasons. Data are for a Mid-Atlantic State protection unit, 1955-1959

JANUARY-MAY, NOVEMBER-DECEMBER

Burning ^{1/} index range	Days	Fires	Acres burned	Fires per day	Acres per day	Acres per fire
----- Number -----						
0 to 10	502	57	124.4	0.1	0.2	2.2
11 to 20	238	148	885.3	0.6	3.7	6.0
25 to 40	173	258	1,077.6	1.5	6.2	4.2
45 to 80	125	450	2,930.7	3.6	23.4	6.5
85+	23	180	1,676.3	7.8	72.9	9.3
Total	1,061	1,093	6,694.3			

JUNE-OCTOBER

0 to 10	612	59	102.4	0.1	0.2	1.7
11 to 20	119	60	185.7	0.5	1.6	3.1
25 to 40	32	52	89.4	1.6	2.8	1.7
45 to 80	2	3	3.3	1.5	1.6	1.1
85+	0	0	0	0	0	0
Total	765	174	380.8			

^{1/} Type 8 meter. It has a 200-point burning index scale.

Basic data for analyses are already available to 13 Northeastern States from yearly analysis reports of fires and fire danger. These are prepared at the Southeastern Station in cooperation with Region 7 of the Forest Service and the Northeastern States. In the reports, number of days, fires, and acres burned are tabulated for months and protection units by burning index as in figure 1. Inspection of monthly values will suggest the grouping of months that will give the best seasonal averages. Burning indexes can, of course, be combined into ranges as desired.

After the probabilities of fire occurrence and size of fires by burning index ranges have been calculated, it is possible to develop a fire organization placement plan with considerable confidence. In preparing it, additional factors must be considered, such as areas of past fire concentration, accessibility, probability of normal or high risk, visibility, and values at stake. Its workability depends to a large extent on how well the planner knows his area, his astuteness in analyzing its past fire history, and in anticipating trends. It goes without saying that effective fire control planning requires thorough and continuing study of reliable fire records and of fire behavior in the field.

Burning Index	July			August			September		
	Days	Fires	Acres	Days	Fires	Acres	Days	Fires	Acres
0									
1							1		
2							2		
3							2		
4				1			2		
5				1	3	3.7			
6				1			1	1	0.2
7									
8				1	2	1.7	1		
9									
10									
11							1		
12				1	2	1.7	1		
13									
14				2	3	3.9			
15							1	1	3.0
16	1	1	2.0				1		
17									
20				4	19	21.6	2	1	.2
25	2	3	3.4	1	3	5.4	2	2	.7
30	2	13	41.0	5	23	33.8	1	3	33.2
35	4	7	15.1	1	8	7.9	1	3	9.5
40	4	20	36.0	3	20	18.3	1	8	28.1
45	3	6	4.9	1	4	628.0			
50	5	28	114.0	1	7	59.4	2	19	153.5
55	1	1	.2	2	10	9.5			
60	1	1	.2				1	8	509.2
65									
70	2	13	17.1	1	9	6.9			
75									
80	1	8	21.8	1	7	12.6			
85									
90									
95									
100+	4	41	560.4	1	4	6.7			
Unknown	1			3	1	.5	7		
TOTAL	31	142	816.1	31	125	821.6	30	46	737.6

Total

B.I. 1,596

928

442

Figure 1.--Sample report showing number of days, fires, and acres burned by months and burning index. Data are for a Northeast State protection unit, 1957.

Although placement plans can be developed on the basis of burning index alone, ranger districts on Eastern national forests have successfully used plans based on preparedness classes.^{2/} In these (fig. 2), burning and buildup indexes were combined to integrate probability of fire occurrence, rate of spread, and resistance to control into five readily identifiable categories of increasing job load. Figure 3 is a sample placement plan for a hypothetical protection unit.

^{2/} Developed by J. J. Keetch.

PRELIMINARY PREPAREDNESS SCHEDULE
(For use on the National Forests of Region 7)

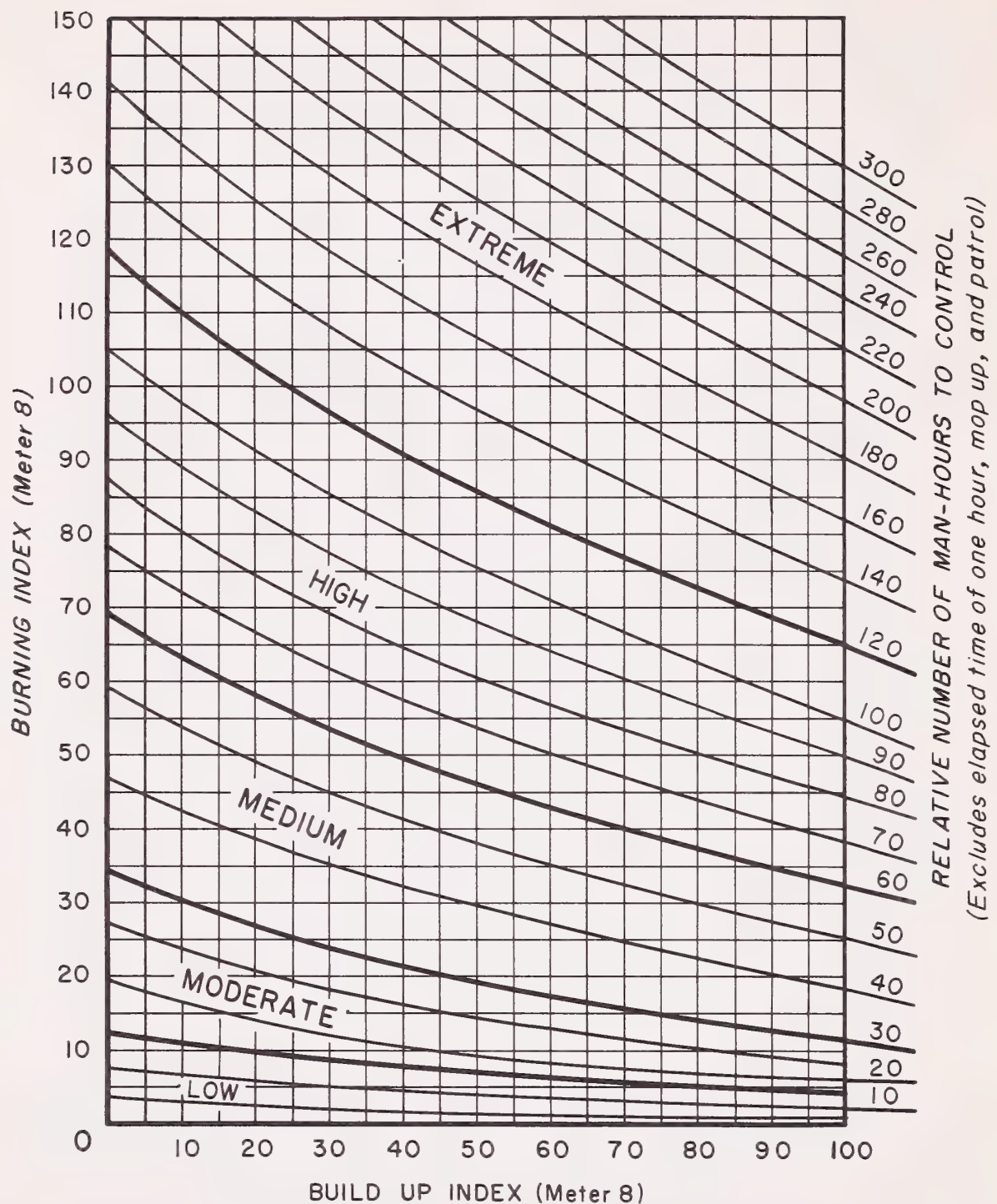


Figure 2.--Preparedness classes.

A plan such as illustrated has numerous advantages. The unit manager is better able to maintain tight control over his men and to better organize their work both for off-fire and on-fire duty. There is less chance that he will be caught unprepared by an unusual fire situation. A well-conceived plan should reduce the probability of either overmanning or undermanning and should, in the long run, make for a more effective and economical fire control program.

Position	Preparedness Classes									
	Low		Moderate		Medium		High		Extreme	
	Normal risk	High risk	Normal risk	High risk	Normal risk	High risk	Normal risk	High risk	Normal risk	High risk
District Forester	0	0	0	0	1	1	1	2	2	2
Fire Control Ass't.	0	0	1	1	2	2	2	2	2	2
Dispatcher	1	1	1	2	2	2	2	2	2	2
Service Forester	0	0	0	0	1	1	1	2	2	2
County Rangers	1	1	1	2	2	2	2	2	2	2
Lookouts										
A	0	0	2	2	2	2	2	2	2	2
B	0	0	0	2	2	2	2	2	2	2
C	0	0	0	0	0	0	2	2	2	2
Work Crews										
A	0	0	0	1	1	2	2	2	2	2
B	0	0	0	1	1	1	2	2	2	2
Standby Crews										
A	0	0	0	0	0	0	0	2	2	2
B	0	0	0	0	0	0	0	2	2	2
Ground Patrols										
A	0	0	0	0	0	2	1	2	2	2
B	0	0	0	0	0	0	0	2	2	2
Air Patrol	0	0	1	1	1	2	2	2	2	2

Figure 3. --Sample fire organization placement plan for a hypothetical protection unit in a Northeast State during the fire season. Duty status: 0, non-fire duty or off duty; 1, on call and within reach for fire duty; 2, on duty or immediately available for fire duty. High risk may result from concentration of use or other causes; poor visibility may be equivalent to high risk.

PREPAREDNESS CLASSES AS GUIDES TO DISPATCHING

Once a fire is reported, the dispatcher or other fire control officer has the difficult task of deciding on the strength of the initial task force that should be sent. In addition to danger rating, he needs to consider, among other things, the fuel type in which the fire is burning or likely to burn. Both factors have a decided effect on rate of spread and resistance to control and therefore on manpower and equipment requirements.

Major fuel types in Eastern national forests have been classified according to rate of spread and resistance to control and have been assigned a fuel type factor (table 3).

Table 3.--Fuel type classification by rate of spread and resistance to control, Region 7

Fuel type factor	Fuel type	Rate of spread	Resistance to control
1.0	Grass, ferns, weeds	High to extreme	Low
1.0	Hardwood, pine or pine-hardwood litter	Medium	Medium
2.0	Hardwood slash or blowdown	Medium	High
2.5	Pine or pine-hardwood slash or blowdown	High	High
3.0	Scrub oak	Extreme	Medium to high
3.0	Northern conifer reproduction	Extreme	High
3.5 to 4.0	Laurel and rhododendron	High to extreme	High to extreme
4.5 to 5.0	Northern conifer slash	High to extreme	Extreme

Referring to figure 2, the numbers on the right-hand margin indicate the estimated number of man-hours required to control a fire having a rate of perimeter increase equal to the fastest spreading 25 percent of the fires. The figures are also based on an assumed one-hour elapsed time (time of origin to first attack), control time of one hour, and a fuel type factor of 1.

Because the rate of perimeter increase is an average of the fastest spreading 25 percent of the fires in all fuel types, the man-hour values need to be adjusted according to the fuel type factor. Other considerations entering the dispatcher's calculations are estimated travel time and the desired time to control the fire (5 to 8 hours).

The following sample calculation illustrates the procedures that have been used by Eastern national forests to estimate the number of line workers needed:

(1) Burning index (meter 8)	30
(2) Buildup index	45
(3) Man-hours (fig. 2)	40
(4) Estimated travel time	1.5 hours
(5) Fuel type factor	1.0 (hardwood litter)
(6) Adjusted man-hours (40 x 1.5 x 1.0)	60
(7) Desired control time	5 hours
(8) Number of line workers (60 ÷ 5 = 12)	12

These calculations are simple enough but they can by no means be more than a general guide to the dispatcher. He must take into account such variables as skill and endurance of available line workers, probable increase or decrease in severity of burning conditions, slope which has the same effect on rate of spread as an increase in wind speed of several miles per hour, and values at stake. Furthermore, the procedure outlined allows for some margin of safety because it is based on the fastest spreading 25 percent of the fires. For the average fire in relatively flat terrain, some overmanning might result; for steep slopes, some undermanning.

The discussion so far has not considered the fires that spot or crown. These can be described as three-dimensional and have behavior characteristics entirely different from the usual surface fire. No way of estimating their behavior has yet been discovered but even so the burning and buildup indexes do provide some degree of warning.

DANGER RATINGS IN FIRE PREVENTION PLANNING

Many fire control organizations use danger ratings as a means of informing the public about the severity of current burning conditions. Most common communication media are newspaper articles, radio and television broadcasts, and a variety of signs indicating the day's danger with an appropriate message as to its meaning. In the Northeast, broadcasts have been used extensively. Some states provide cooperating stations with messages keyed to the day's expected danger:

Today's fire danger will be high to extreme. The forests are very dry and burning conditions are critical. Brush pile or trash burning should not be attempted under any circumstances, and smokers should be extremely careful. The slightest spark will readily ignite a fire in all types of cover. Fires will burn rapidly with intense heat, and some crowning may occur in pine stands that will kill reproduction and cause great damage to standing timber. Burning today is an invitation to trouble.

The assumption is that prevention messages for specific times and places are more effective than generalized programs. Although the value of a particular prevention activity is hard to appraise, it seems reasonable to suppose that forthright appeals to the public during critical periods have some dissuading effect on potential fire starters.

Unfortunately, the rural segment of the public that start most of the fires in the South are not so easily reached by these media as people in more highly urbanized areas. Person-to-person contacts and strict law enforcement will likely continue to be the most potent deterrents to fire starters in the South, at least until much better lines of communication are established.

A number of states have laws empowering Governors to close forests to unauthorized use when danger from fires becomes acute. Regional foresters have similar authority to close national forests. The difficulty lies in knowing how near conditions are to the breaking point so that closure is justified. Decisions are not easily reached. Those in authority realize that closure disrupts people's plans and can cause considerable financial hardship to individuals who supply goods and services to campers, hunters, fishermen, and other woods users and workers. Another difficulty is that closure cannot be quickly invoked. The public must be given reasonable notice and there must be better than a fair chance that difficult conditions will prevail for at least some days.

The buildup index has been found to be a useful guide to woods closure during critical conditions. This is because it is an indicator of the relative dryness of the whole fuel layer (except in organic soils) and unlike the burning index is not affected by changes in wind speed and only to a slight extent by light rains. Consequently, a rising buildup index indicates an increasing potential danger. No specific point on the 100-point scale can be considered critical. However, from past experience in the Northeast, consideration should be given to closure as the index approaches 50. In one state during the difficult 1950-1952 period, 6 closures averaged an index of 52.

In contemplating closure, cooperation should, of course, be requested from the U. S. Weather Bureau fire-weather forecasters. Their 5-day predictions, especially as to the probability of rain or high winds, may well be the deciding factor.

EVALUATING FIRE PREVENTION EFFORTS

Many millions of dollars are spent in forest fire prevention each year. Efforts range from elaborate national publicity programs to person-to-person contacts. Although fire control agencies annually report number of fires and acres burned, and compare one year with another, such comparisons are relatively meaningless unless the effect of weather is taken out. One year may have much more or less severe fire weather than another and a decrease in number of fires over the past year may in reality be because of easy weather rather than the quality of the prevention job.

Through a cooperative project among 13 Northeastern States, Forest Service Region 7, and the Southeastern Station, an analysis of the relation of number of fires and acres burned to burning index has been made for the last 17 years, 1943-1959. One part of the analysis has been to determine the trend in number of fires per thousand units of burning index (occurrence rate). Figure 4 indicates such a trend for one of the Northeastern States. The pronounced downward trend clearly indicates that prevention efforts, of whatever kind, have brought about notable results. A weakness in the analysis is that we cannot yet measure the trend in risk, that is, the increase or decrease in activity of fire starters. However, it can safely be assumed that there has been an increase in the number of woods visitors and users, and therefore potential fire starters, during the 17-year period. On this assumption the decrease in fire occurrence rate is even more striking.

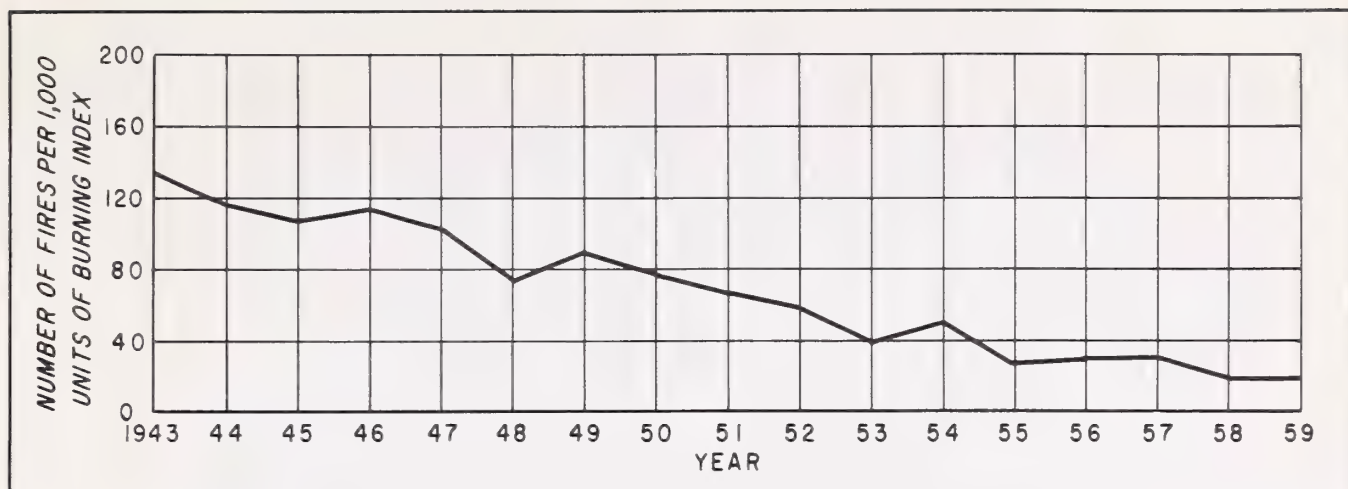
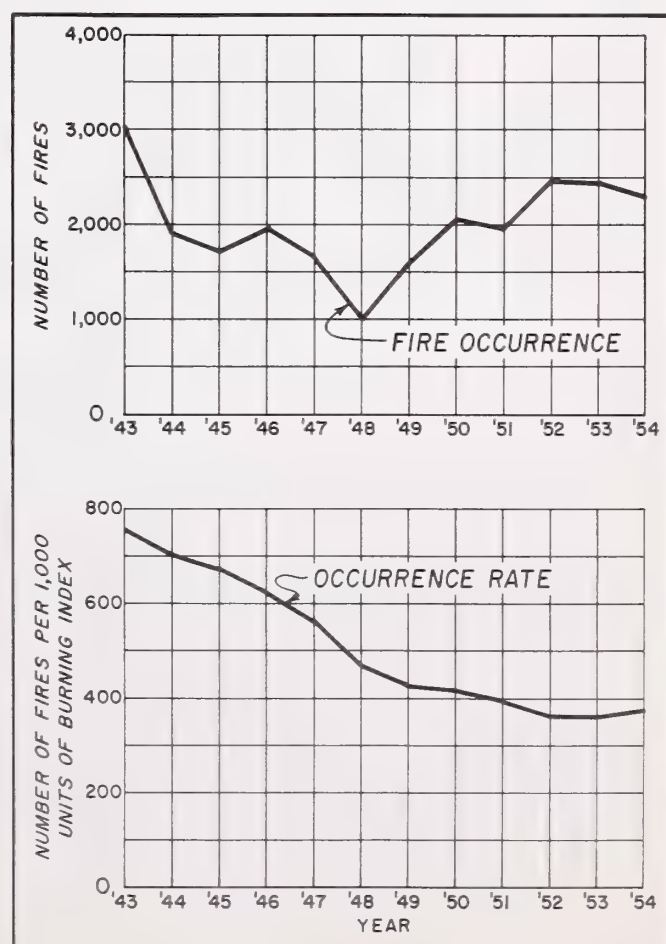


Figure 4.--Fire occurrence rate in a Northeast State by years.

The procedure used for calculating occurrence rate is simple. All that is needed is an accurate record of number of fires by dates and an adequate sampling of fire danger in a protection unit by means of properly located and operated danger stations. The total number of units of burning index, in thousands, are summed and averaged for the year and divided into the number of fires. Adjustment must of course be made if there has been a change in the number of acres protected.

Figure 5, showing how a graph of fire occurrence only can be misleading, is taken from an article by Keetch (3). The upper graph has no discernible trend and one could assume from it that no progress in fire prevention had been made during the 12-year period. Yet, in the lower graph, where the effect of weather has been taken out, it is seen that the opposite is true.

Figure 5.--Fire occurrence and occurrence rate in 13 Northeast States by years (3).



Plotted trends of occurrence rate by years can be very revealing to a fire control manager. A state or regional graph will indicate whether prevention ground is being gained or lost for the large unit as a whole, but will not pinpoint, as will graphs for individual subunits, the areas where prevention activities need to be strengthened or modified. However, subunits should not be so small that trends are likely to be obscured because of relatively few fires.

EVALUATING FIRE SUPPRESSION EFFORTS

A calculation of trends in the relation between danger ratings and acres burned can be used to judge the effectiveness of suppression efforts over a period of years. Such trends for a Northeastern State protection unit are illustrated in figure 6. A 3-year moving average was used to obtain a better measure of trend.

As in evaluating prevention efforts, the effect of weather was taken out in determining the trends in figure 6. With Class E fires eliminated from the computations, it is clear that there has been a very sizeable reduction in number of acres burned per thousand units of burning index. This fact, by itself, does not necessarily indicate the degree of efficiency of the organization, but that an increasingly higher level of fire protection is being obtained.

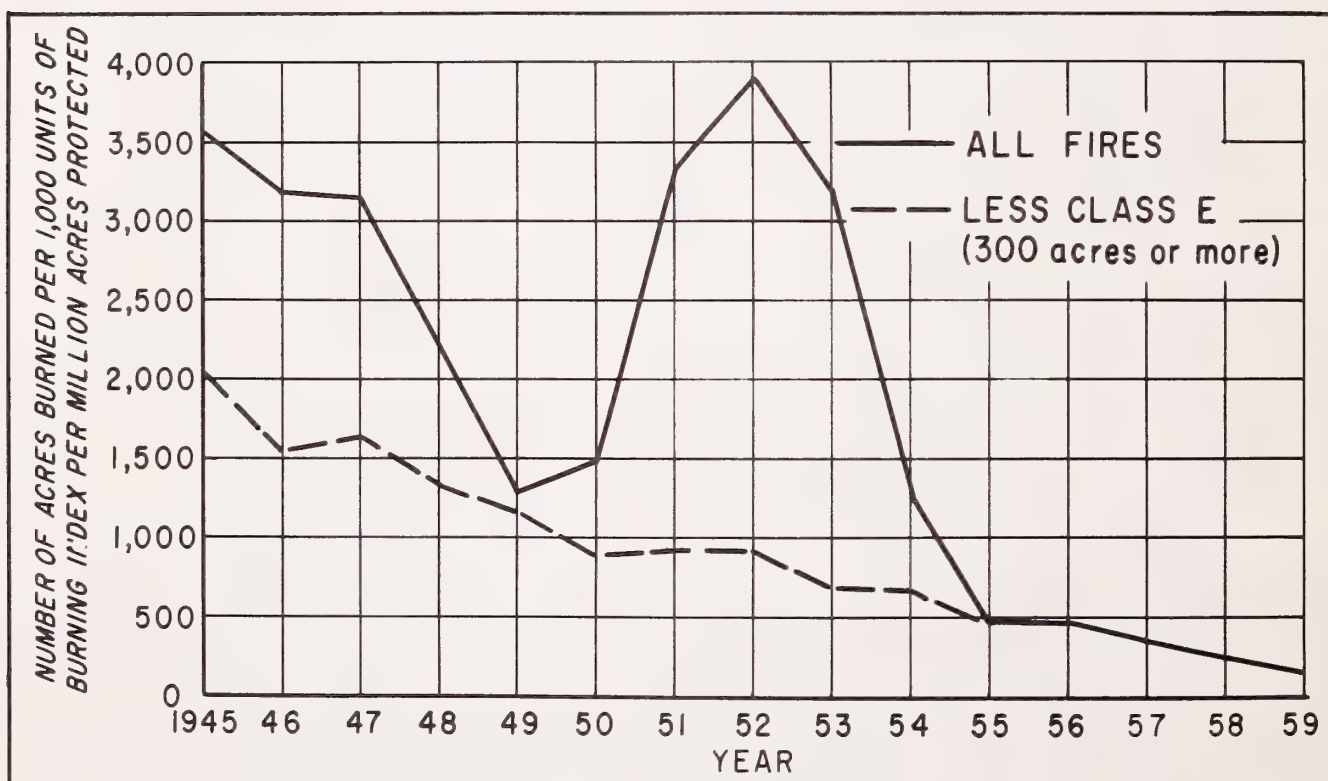


Figure 6. --Burned area rate in a Northeast State by years.
Three-year moving average.

The following procedure was used in calculating the values in figure 6. Total number of fires per year was divided by the total number of burning index units in thousands per year, and this figure in turn was divided by the area protected in the unit in millions of acres as in the following tabulation. This unit had 0.434 million acres.

<u>Year</u>	<u>Total acres burned</u>	<u>Burning index (Thousand units)</u>	<u>Burned area rate</u>	<u>Burned area rate per million acres protected</u>
1957	1,145	7.900	145	334
1958	181	3.857	47	108
1959	213	4.429	48	111

The sum of the figures in the last column is 553; the average, 184, is the value plotted for 1959 in figure 6.

In evaluating fire suppression efforts, as well as prevention efforts discussed earlier, a fire control supervisor has the means of reaching an unbiased opinion as to the relative effectiveness of one unit compared with another. Consequently, he should be able to exercise a higher level of managerial control from a recognition of strong as well as weak units in his organization.

RATING YEARS BY SEVERITY OF FIRE WEATHER

One year can be rated against another, or against a "normal" year, according to the severity of fire weather if good records for a number of years are available. The larger the number of years, the better the rating; five should probably be the minimum.

Burning indexes for a single month for a number of years are ranked in order of magnitude and the middle value (median) is taken as the "normal" burning index. For example, if values for 9 years are ranked, the fifth item would be the median; if 10 years are ranked the median would be an average of the 5th and 6th items. In these calculations, medians are preferred to averages because they are not distorted by an exceptionally high or low value.

Monthly medians are summed to obtain the normal burning index for the period. Dividing the total burning index for any one year by the normal index gives a percent figure that establishes that year's rating on the basis of the severity of fire weather. Medians for individual months can, of course, be grouped as desired to provide season ratings.

Figure 7 is a plot of yearly ratings for a Northeastern State. From it the relative severity of fire weather for each year can be seen at a glance.

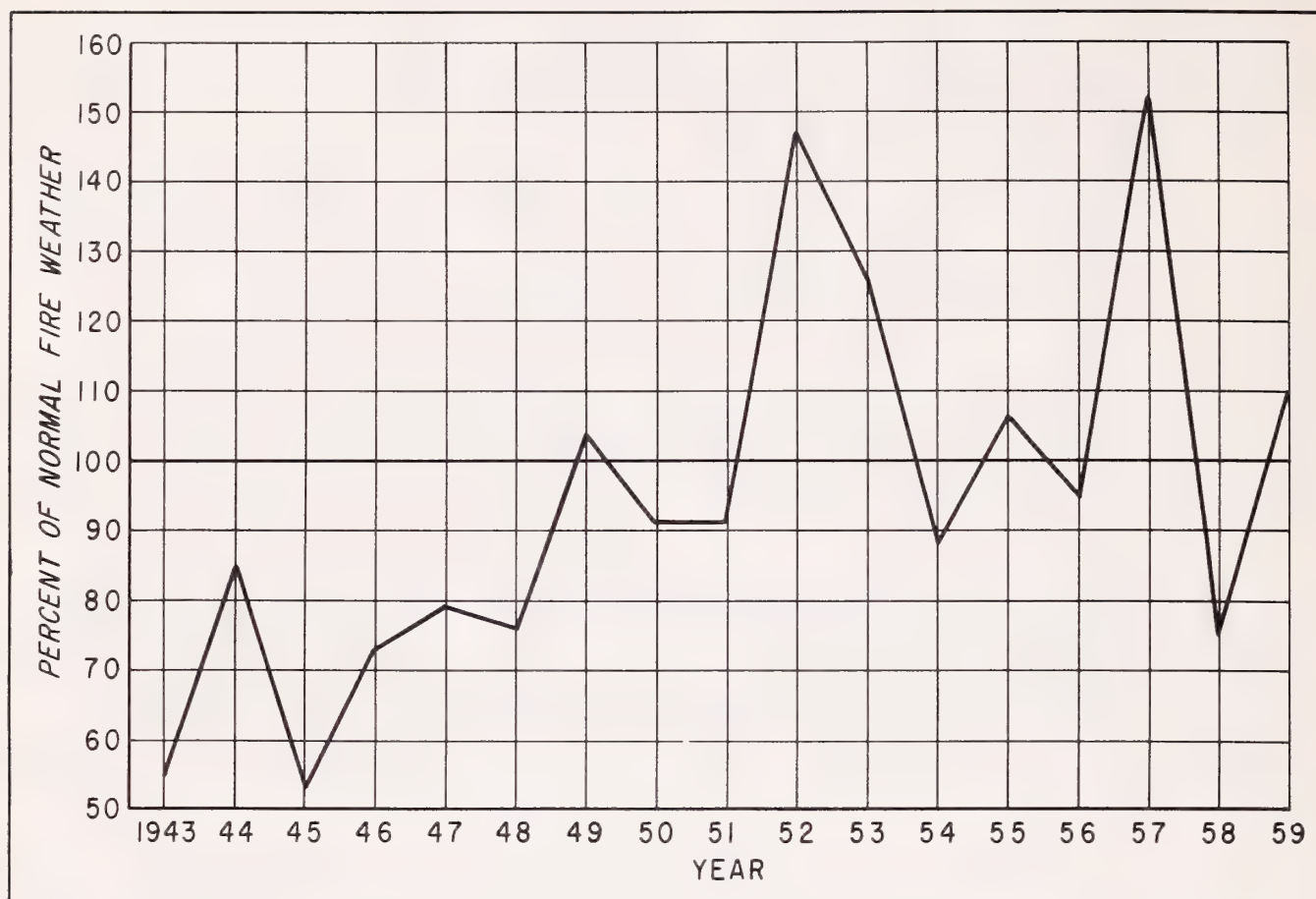


Figure 7. -- Fire weather ratings for a Northeast State by years.

EXTREME FIRE BEHAVIOR

For the Nation as a whole, five percent of all forest fires burn an estimated three-fourths of the acres lost and cause even a greater percent of the damage. Most of this small percent of fires exhibit extreme behavior and are often characterized by strong convection columns, whirlwinds, violent updrafts and downdrafts, long-distance spotting and, therefore, very high rates of spread. Most fatalities among firefighters occur because of the unbelievable rate of energy release and unpredictable behavior of such fires. Moreover, the cost of control of a single fire sometimes runs into millions of dollars. Most certainly, the elimination of disaster fires is the one most pressing problem facing the Nation's forest fire control agencies.

Byram's (1) analysis work, as well as his case history study of blowup fires, indicates that certain fuel and atmospheric conditions are conducive to extreme fire behavior. Briefly, a fire has blowup potentialities when it is burning in an area of abundant dry fuel and where the speed of the winds near the surface (usually less than 1,500 feet above the fire) exceeds the speed of winds aloft. Apparently for any given wind speed, a critical rate of energy release must be reached before large-scale convection can begin. The geographic extent and periodicity of wind profiles conducive to convection are not known nor can they yet be predicted. There is evidence that adverse pro-

files most often come with winds from the Southwest and Northwest quadrants. The worst conditions appear to accompany the passage of dry cold fronts at which time the wind is usually from the Northwest or North.

None of the blowup fires in the Northeastern States studied so far have burned when both burning and buildup indexes (on the 200-point type-8 meter) were below 50. From an examination of many years of records, these indexes were reached on only 5 percent of the days. Therefore, the best insurance against disaster fires would seem to be extremely fast attack on this small percent of days of high indexes so as to contain fires, especially those in heavy fuels, before they can reach the "triggering-off" stage.

The practice of prescribed burning for fuel reduction and other purposes undoubtedly lessens the probability of conflagration-type fires in the South.

As technical advances are made in fire-weather forecasting, prediction of these extremely dangerous periods should become possible. When that time comes, with the exercise of utmost vigilance and fast attack, the probability of disaster fires should lessen in the East and South.

COMPUTING METHODS FOR FOREST FIRE AND FIRE DANGER RECORDS

Earlier sections of this paper have explained the relation of danger ratings to fire occurrence and acres burned and the several applications of these relations. The step-by-step procedures that have been developed for handling raw data are not complicated. Over the years a number of forms and methods have been devised that greatly facilitate analysis work. They are currently used in the annual preparation of forest fire and fire danger reports for 13 Northeastern States.

- (1) Fire danger daily records, such as figure 8, are received from reporting danger stations at the end of each month. Condition of lesser vegetation (col. 2) is first checked because it is one of the items that causes much trouble. Observers have little difficulty in deciding when vegetation is fully green or fully cured, but during transition periods they often fail to follow instructions that have been issued (2, 8). Other items checked are the buildup factors, subtraction from the buildup index because of rain, and the burning index by setting up individual daily factors on the danger meter.
- (2) The next step is to calculate the average burning index for each protection unit. This is done on the sample summary form (fig. 9). For the purpose of illustration, assume a small state with two protection units and three danger stations in each unit. The highest burning index for each day and station are entered on the summary form from the fire danger daily record and averages obtained as shown in the right-hand columns in figure 9. Averages must be rounded off to the near-

FIRE DANGER DAILY RECORD

April 1954
(month)

Sample (State or Forest)					Sample (District)			Sample (Open) (Station)					John Doe (Observer)			
Day of the Month	Condition of the Lesser Vegetation	9 A.M. EST			24 HOUR RAINFALL 2 P.M. TO 2 P.M. (Hundredths)			2 P.M. EST					5 P.M. EST			
		Fuel Moisture Percent	Wind Speed Miles per Hour	Burning Index	Amount of Rain Danger Station	Amount of Rain Coop. Station	Average Amount of Rainfall	Build-up Index	Build-up Factor	Fuel Moisture Percent	Wind Speed Miles per Hour	Burning Index	Fuel Moisture Percent	Wind Speed Miles per Hour	Burning Index	Highest Burning Index for the Day
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1	50+	8.0	1	13	25	19	15	5	6.0	6.5	35	5.3	7.0	40	40
2	1	11.0	5.0	10			0	23	8	4.0	8.0	75	3.6	6.0	65	75
3	1	8.5	3.5	15			0	29	6	5.0	5.0	50	5.0	6.5	60	60
4	1	50+	8.0	1	85	45	65	2	2	11.8	8.5	7	10.2	8.5	10	10
5	1	11.7	8.5	8			0	5	3	8.0	9.0	20	8.2	8.5	20	20
6	1	10.0	5.0	7			0	13	8	4.0	6.0	45	4.0	4.0	30	45
7	1	12.2	8.5	12	T	T	0	18	5	6.0	4.5	30	5.6	5.0	35	35
8	1	13.0	5.5	8			0	26	8	4.8	5.5	50	4.3	5.0	50	50
9	1	14.2	3.0	4			0	34	8	4.1	5.0	60	4.5	5.0	60	60
10																
11																
12																

Figure 8.--Sample fire danger daily record. Meter type 8.

est burning index figure shown on the meter. Missing records are entered as dashes; snow on the ground as 0. For example, on the 6th day, the average is of two items for Unit X, but of three for Unit Y.

- (3) Shortly after the end of each year, cooperating states forward code sheets similar to figure 10 to the Southeastern Station. Each line on the form is for a single fire. For example, the first entry on the sample form means the protection unit "X" had a 0.3 acre fire on January 24 that was caused by a debris burner. The average burning index for the unit on that day was 11. This last item is entered on the code sheet after completion of step 2.
- (4) Data from each line on the code sheets are punched on individual IBM-type cards, which are machine sorted and tabulated. The tabulation sheets indicate the number of fires and acres burned by protection units, months, and burning index. This information is entered on work sheets such as figure 1. The number of days by burning index for each month is taken from unit averages on the summary forms previ-

FOREST FIRE DANGER SUMMARY

Forest or State _____					Sample _____					Month _____					Sample _____, 19____				
DAY	Unit X					Unit Y								Unit X ave.		Unit Y ave.			
	A	B	C	Total		D	E	F	Total										
1	25	30	55	110		17	20	60	97					35		30			
2	30	30	25	85		13	17	40	70					30		25			
3	35	30	50	115		20	60	17	97					40		30			
4	35	25	40	100		25	30	50	105					35		35			
5	38	16	30	76		30	20	30	80					25		25			
6	5	5	-	10		5	5	0	10					5		3			

Figure 9.--Sample fire danger summary form.

FOREST FIRE CODING SHEET																	Sheet		of					
State			Sample			()		Unit		X			()		Year		()							
County			Burning Index			Month		Day		Cause	Area													
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0	1	3	0	1	1	0	1	2	4	6	0	0	0	0	0	3								
0	1	3	0	1	3	0	1	3	0	5	0	0	0	3	5	0								
0	2	3	0	2	0	0	2	2	7	5	0	0	0	0	1	0								
0	2	3	0	1	5	0	2	2	7	6	0	0	0	0	3	0								
0	2	7	0	3	5	0	2	2	8	6	0	0	0	0	2	0								

Figure 10.--Sample forest fire coding sheet.

ously mentioned. These monthly work sheets contain the basic data and from them number of fires and acres burned can be grouped by seasons and classes of burning index as desired. Data for units can be combined into state totals and these into regional totals.

Protection agencies having ready access to IBM-type equipment may find the tabulating procedure followed by the Southern Forest Fire Laboratory to be superior to the one described because some of the hand sorting is eliminated. In addition to punching a card for each fire, a card containing fire danger data is punched for each day. The daily cards permit machine sorting for number of days by burning index and preparation of a variety of other tabulations.

- (5) A second machine tabulation of number of fires by burning index, cause, and protection unit, permits an examination of causes of fires. Records, such as in figure 11, should aid a unit manager in better directing prevention efforts. Obviously, the value of such information depends on how well the causes of individual fires are known and reported.

Range in burning index	Light- ning	Rail- road	Lumber- ing	Camp- fire	Smok- ing	Debris burning	Incen- diary	Misc.	Un- known	All causes
----- Number -----										
<u>Eastern District</u>										
0-10	1				3	2		1		7
11-20					3	4	1	4		12
25-40				1	1	6	1	3		12
45-80				3	6	15	8	9		41
85-160					4	8	5	8		25
Unknown										
Total	1			4	17	35	15	25		97
<u>Western District</u>										
0-10					5	9		5		19
11-20					7	6	1	5		19
25-40		2		1	14	37	7	23		84
45-80		4		7	28	53	11	40		143
85-160	1	2			16	31	8	13		71
Unknown		1			3	9	1	5		19
Total	1	9		8	73	145	28	91		355
<u>State Totals</u>										
0-10	1				8	11		6		26
11-20					10	10	2	9		31
25-40		2		2	15	43	8	26		96
45-80		4		10	34	68	19	49		184
85-160	1	2			20	39	13	21		96
Unknown		1			3	9	1	5		19
Total	2	9		12	90	180	43	116		452

Figure 11.--Sample tally sheet showing number of fires by cause and burning index ranges. Data are for a Northeast State.

USE OF DANGER RATINGS IN FIRE DAMAGE APPRAISAL

No accurate yet practicable method for appraising damage caused by individual fires has so far been devised. This is partly because of the infinite variety of fuel and stand conditions and fire intensity that are found and partly because of inability to assess damages to so-called intangibles, such as recreation, wildlife, watershed, soil, and esthetic values.

In spite of limitations imposed by lack of knowledge of fire effects, a set of damage appraisal tables (7) were prepared that have been widely used in the East and South. The tables are based on average stand values and average stand losses. If adjusted to current stumpage prices, they provide a fairly acceptable means of estimating dollar losses caused by large groups of fires.

Burning index is one of the major variables in the tables because, in general, the higher the burning index the greater the fire intensity and hence, greater physical damage to the stand (fig. 12). As an example, an April fire in a satisfactorily stocked pine-hardwood stand, predominantly in the 2- to 4-inch diameter class, is estimated to cause 6 times the dollar loss on a day with a burning index of 70 than on a day with an index of 2.

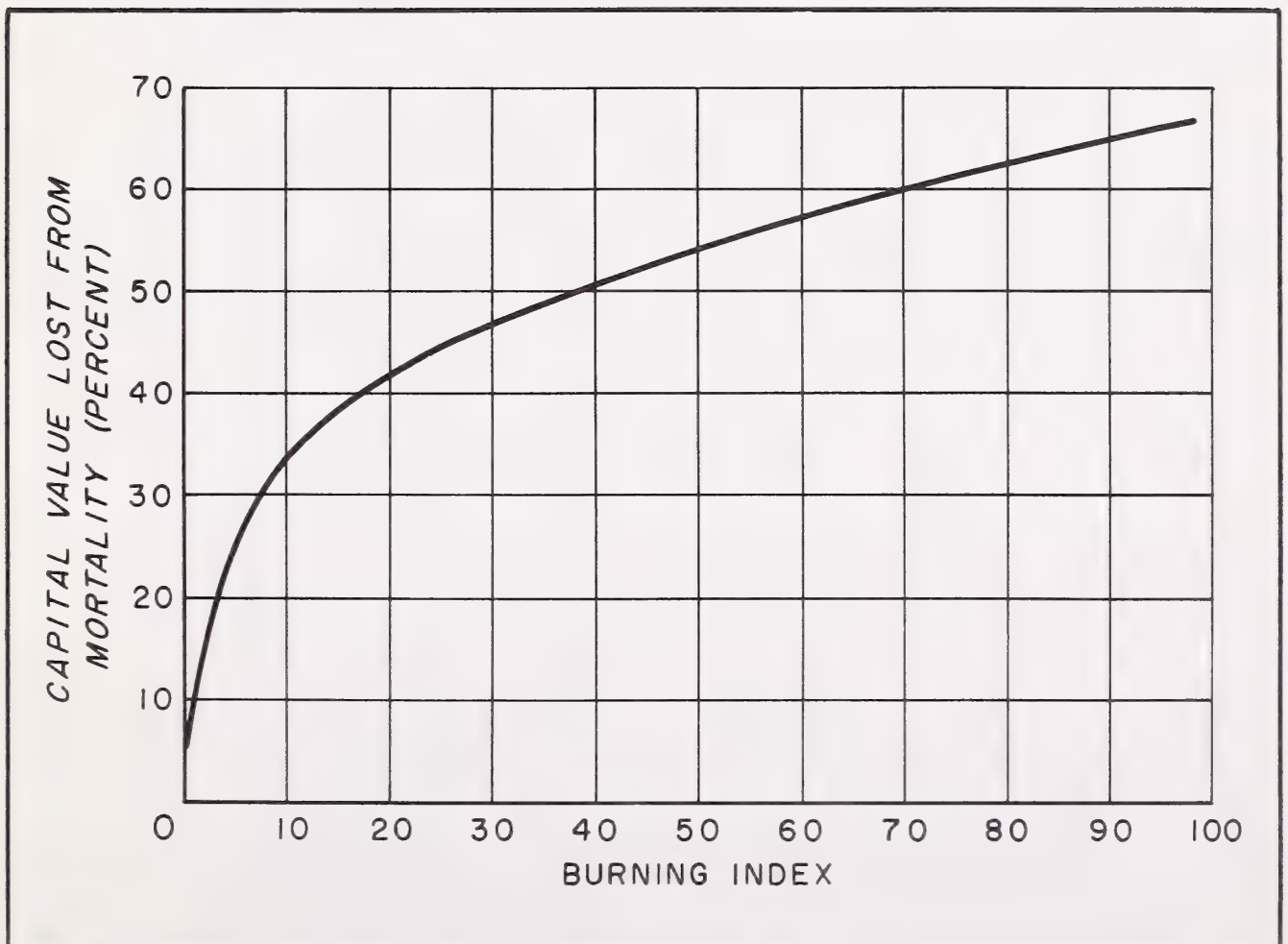


Figure 12.--Fire damage in young pine stands is correlated with burning index.

DANGER RATINGS AS A PARTIAL GUIDE TO AIR PATROL

Increasing use is being made of aircraft patrols in the South. Because of speed and versatility, they can save much effort in checking smokes to determine whether suppression action by ground forces is needed and in scouting the progress of large fires. Aircraft are also used to supplement tower detection during periods of low ground visibility and in various aspects of fire prevention and law enforcement.

A fire control manager needs guidelines to help him decide how best to budget flying time so as to buy the most protection for his money. Other things being equal, it can be assumed that air patrols should be made on days and during hours when the probability of fire occurrence is greatest. As has been indicated in earlier parts of this paper, there is a positive relation between burning index and fire occurrence; that is, as the index increases, the probability of fires also increases.

A method (9) for developing the use of burning indexes as partial guides to aircraft patrol is illustrated in table 4. In column (1) days were arranged according to burning index, cumulated upward in column (2), and percents were calculated in column (3). For purposes of this analysis, a 5-month period, January through April and December, was selected because these were the most severe months. The whole year or a combination of other months could, of course, have been used as desired; the procedure would have been the same. Fires were similarly arranged in columns (4), (5), and (6).

Table 4. --Relation between number and percent of patrol days and fires and burning index for the period January through April and December, 1959. Data are for a protection unit in a Southern State

Burning index	Days	Days cumulated	Days	Fires	Fires cumulated	Fires	Fires adjusted
	Number	Number	Percent	Number	Number	Percent	Percent
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	26	151	100	8	509	100	76
2	8	125	83	3	501	98	74
3	9	117	77	11	498	98	74
4	12	108	72	47	487	96	73
5	11	96	64	52	440	86	65
6	11	85	56	66	388	76	58
7	7	74	49	20	322	63	48
8	9	67	44	34	302	59	45
9	4	58	38	42	268	53	40
10	4	54	36	18	226	44	33
11	5	50	33	27	208	41	31
12	5	45	30	49	181	36	27
13	3	40	26	15	132	26	20
14	4	37	25	8	117	23	17
15	2	33	22	3	109	21	16
16	6	31	21	34	106	21	16
17	2	25	17	8	72	14	11
20	7	23	15	24	64	13	10
25	11	16	11	34	40	8	6
30	3	5	3	4	6	1	1
35	2	2	1	2	2	0.4	0.3

The next step was to determine the percent of fires by hour of origin and to consider the number of hours that a pilot and observer could fly without undue fatigue. Five hours were taken to be a reasonable stint and the period from noon to 5 p.m. proved to have the greatest concentration (76 percent) of the fires. The values in column (6) were accordingly multiplied by 0.76 to give adjusted values in column (7).

From table 4 it is possible to compare different percents of patrol days with regard to number of fires that occurred and burning index. For example, had patrols been made on about half of the days (49 percent, column (3)), flying would have had to be done on all days having a burning index of 7 or more. On these days, and between noon and 5 p.m., about half the fires (48 percent, column (7)) occurred and would theoretically have been observable.

Factors other than the probability of fire occurrence must, of course, be considered by the fire control manager in deciding when and where air patrols should be made. These include budget limitations, low ground visibility, probability of increased activity by potential fire starters, hot spots or blind areas, and values at stake.

Analyses such as described must be made of several years of records before a reasonably satisfactory operations guide can be developed.

FIRE-WEATHER FORECAST SERVICES

Little mention has so far been made of the excellent services provided by U. S. Weather Bureau fire-weather forecasters. The field man may be fully aware of the severity of today's burning conditions, but he has little basis for estimating tomorrow's conditions except as he may have access to fire-weather forecasts.

Four fire-weather forecast centers have been established in the East and South. These are: Boston, Massachusetts; Asheville, North Carolina; Macon, Georgia; and Tallahassee, Florida. Although routinely issued forecasts are of necessity for fairly large geographic areas, forecasts can be pinpointed if fire control men so request. If emergency conditions exist, or in the event of a project fire, special forecasts will be prepared at any time provided the forecaster is informed as to specific weather information wanted for a specific area.

The following is a brief summary of procedures followed by the Asheville center. Other centers may have somewhat different routines. Facsimile weather maps of surface and upper air conditions arrive periodically during the day from the National Weather Analysis Center in Washington, D. C. These are supplemented by synopses of weather conditions and guidance forecasts by teletype from the National Weather Analysis Center and from a number of forecasting centers. Pilot balloon observations are received every six hours and radiosonde data at 12-hour intervals. During fire seasons, fire danger

measurements are received from approximately 100 selected danger stations, operated by state and federal agencies in a 6-state area, at about 2 p.m. by telegraph or telephone. The forecaster thus has a wealth of weather information which must be digested and interpreted in terms that will be useful to fire control men.

In ordinary years the fire season extends from February 15 through May 15 and from October 15 through December 5. However, dates are altered as needed to meet unusual fire situations. During these seasons, daily forecasts from Monday through Saturday are issued at about noon for the afternoon, evening, and following day. On Monday, Wednesday, and Friday, four-day outlooks are issued that indicate the principal weather changes expected. A standby watch is on duty on Sunday from 6 a.m. to 6 p.m. Forecasts are transmitted by telegraph or telephone from Asheville to designated offices of using agencies who then distribute them to field units.

Items included in the forecast for the day are cloud cover, precipitation expected, minimum fuel moisture, maximum temperature, and maximum wind speed and direction at open-type danger stations. Forecasts for the night include cloud cover, indicated precipitation, minimum temperature, wind direction and lowest speed, and maximum fuel moisture. Other items of weather information are sometimes added, such as expected wind shifts and the probable time of shift. These forecasts enable the fire control man to set up weather information on his fire danger meter and so to determine the probable buildup and burning indexes for the period ahead.

Special forecasts are prepared whenever requested. Field men sometimes ask questions, such as: "Will the weather hold during the next 12 to 18 hours?" "Will conditions be favorable for backfiring tonight?" "Is a change in wind direction expected so that I will need to shift the crews?" Such questions are gladly answered by the forecaster to the best of his ability but he is not likely to be particularly pleased when services are requested during periods of high danger only after a fire burns out of control.

Limited forecasting services can be obtained from Weather Bureau offices in: Montgomery, Alabama; Jackson, Mississippi; Shreveport, Louisiana; Houston, Texas; Fort Smith, Arkansas; Little Rock, Arkansas; Baltimore, Maryland; Hartford, Connecticut; Harrisburg and Philadelphia, Pennsylvania; and Albany, New York. Strongly expanded services can be expected, if funds become available, as a result of a recent National plan developed jointly by the Weather Bureau and the Forest Service.

NEED FOR ACCURATE BASIC RECORDS

Previous sections of this paper have described the applications of fire danger measurements in a variety of fire control activities and have outlined methods of analysis. The writer cannot emphasize too strongly that the value of such analyses depends to a great extent on the accuracy of the basic data.

There is little purpose in a fire control agency spending time and money in locating stations and providing instruments if it is lax in training observers and following up on station operation and maintenance. We have found that there is no substitute for patient training of observers and periodic and thorough inspection of stations. These things are elementary, yet a substantial number of stations in the East and South are substandard and consequently have substandard records.

The criticism directed at inaccuracies in fire danger records apply equally well to fire reports. Number of fires and their dates and locations are probably reported with fair accuracy but acres burned, and particularly causes except for a few categories, are often questionable.

A NATIONAL FIRE DANGER SYSTEM

The desirability of having a National fire danger system rather than a number of regional systems has been recognized for many years. Work in earnest on the project was started in 1958 when a staff position was established in the Washington Office Division of Forest Fire Research in cooperation with the Division of Fire Control (5). Some of the objectives are to provide for better National coordination of fire control plans and more uniformity among planning systems, evaluation and comparison of work loads and allotment of funds, appraisal of fire control performance, and a more meaningful basis for reporting fires, area burned, damages, and expenditures. In addition, a National system will simplify the interpreting of fire danger when men are detailed or transferred from one region to another, and will facilitate better coordination and understanding among cooperating agencies.

Regardless of how weather variables may be integrated with fire phenomena in a National system, the principles of analyzing fire occurrence and behavior under a variety of fire climates will remain the same. The application of these principles should make possible a much better evaluation and comparison of fire problems and progress among regions and provide additional tools for fire control planning on a National scale.

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